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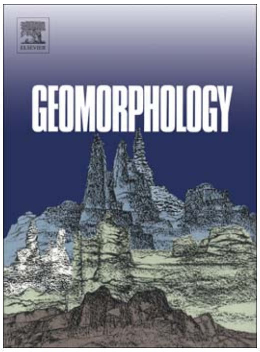

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The Pedological Heritage of the Dolomites (northern Italy): Features, Distribution and Evolution of the Soils, with some implications for land management

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ABSTRACT

Since 1997, the Department of Environmental Sciences of Ca' Foscari University of Venice has undertaken numerous research projects aimed at deepening understanding of pedogenic processes in the Dolomites, and at highlighting the fundamental contribution that soil science can give to the conservation of natural resources and achieve sustainable management of mountain ecosystems. A total of several hundred profiles have been described, analyzed and mapped. This paper reports the results from the analysis of pedo-environmental characters of profiles developed from different parent materials, at altitudes between 1300 m and 2900 m and in different conditions of slope, exposure and vegetation cover. Soil forming factors, landforms and land surfaces have been interpreted to understand the soil-landscape in the mapped areas and to develop a qualitative model of soils geography into the Dolomites scenery. The application of land evaluation methods in some of the investigated territories that are subjected to intensive tourist fluxes revealed some criticisms. Collected results also highlighted the high environmental heterogeneity of soils of the Dolomites.

KEYWORDS: Alpine environment, Dolomites, Soil evolution, Pedogenesis model, Pedogenic factors, Land evaluation

1. INTRODUCTION

The Alpine environment has always attracted human attention, not only for its natural aspects, (rocks, glaciers, flora, fauna and streams), but also for aesthetic reasons through its peerless sceneries of mountain landscapes, where soils contribute with their heterogeneity in morphology, colours and horizons. Soils of the Alpine environment occur extensively throughout the major mountain systems of the world, such as the Alps, the Andes, the Himalayas and the Rocky Mountains, and to lesser degree in other mountainous areas, at elevation ranging between 1500 and 3000 m a.s.l.. In Italy their greater extent is in the Alps (Previtali, 2002), but small areas of such soils occur also in the Apennines Chain (Baroni et al., 1990). In recent years, soils of the Dolomites region, in the eastern Italian Alps, have been studied by several scientists (Zilocchi, 2003; Sartori et al., 2005; Bini et al., 2008; Egli et al., 2008; Merkli et al., 2009), who outlined soil genesis and evolution under different lithological, geomorphologic and climatic conditions. Nevertheless, studies on the geographical distribution, pedological features and processes of soils in the alpine environment, as well as the development of interpretative schemes of the soil variability of the Alps, are far from being complete.

The Dolomites region, in Northern Italy (the name Dolomites comes from the Triassic calcareous rock discovered by the French geologist Dolomieau) is characterized by an enormous variability of soil landscapes, due to the quite young geological structure, to different lithological types and to morphological dynamics (Previtali, 2002; Merkli et al., 2009). Both geological and climatic conditions, as well as anthropogenic activities (e.g. skiing installation, etc.), contribute to landform processes: frequent landslides, rock falls and current erosion processes modify the landscape, and influence soil formation and evolution (Hall et al., 2002; Egli et al., 2003), besides posing serious threats to local people and to tourists.

The variety of the Dolomites landscape, deriving from the combination of different rocks, steep slopes and gentle footslopes, pasture and forest stands or dry and bare meadows (Sburlino et al., 1999), is known all over the world, and was recently (2009) recognised by the UNESCO as a World Human Heritage. The complexity of the geology adds difficulty to the study of the soil cover of the area, but at the same time it makes it extremely interesting, and allows a complete panorama of soils in this mountain and alpine environment.

In this work, most effort is concentrated on alpine and subalpine soils located in the centre of the Dolomites Group, at elevations ranging between 1500 and 2400 m a.s.l.. The main objective of the study is the characterization of the soils of the Dolomites mountains. In relation to this objective, it is possible: i) to investigate the role of the different soil forming factors and processes in the alpine environment, and ii) to develop a qualitative model of soil evolution and geography in the Dolomites landscape.

Soils are fundamental components of ecosystems. The stability of mountain ecosystems depends primarily on soil conservation. Alpine soils are of particular concern because of their potential role in neutralizing acid deposition (Rochette et al., 1988; Briggs et al., 1989), in acting as a sink for atmospheric carbon dioxide (Garlato et al., 2009), and contributing to slope stability and protection from erosion (Harden, 2001; Bini et al., 2010), through the maintenance of traditional agricultural and forest activities.

A second objective of this study, therefore, is to assess the role and function of soil in controlling the geomorphologic fragility of the terrain, where increasing number of tourists, changes in land use, and climate change are expected to intensify soil erosion (Bosco et al., 2009). This objective may be achieved by evaluating the actual soil erosion hazard, and the land suitability for different land uses (e.g. agriculture, forestry, pasture, and tourism), thus providing useful tools in soil protection strategies and sustainable land planning.

2. STUDY AREA

The Dolomites' range is located in the northeast region of the Italian Alps (Fig. 1, Table 1), where it covers approximately 140,000 ha, including eighteen peaks which rise to above 3,000 meters. Elevation ranges between 900 and 3400 m (Marmolada Glacier). Because of the landscape's exceptional beauty, the scientific relevance, and based on their outstanding universal value, the Dolomites have been added to UNESCO's World Heritage List in June 2009. Within the whole area designated by UNESCO, six reference sites located in the central part have been selected on the basis of their great geological and geomorphologic variability (Bosellini, 1996), with a close connection between rocks, landforms, vegetation cover and soil development. The selected areas, moreover, also represent some of the most naturalistically and economically important areas of the Dolomites, among which Cortina is known as the Dolomites' pearl, one of the most famous tourism places in the world.

2.1. GEOLOGY AND GEOMORPHOLOGY

The geology and lithology strongly influence the geomorphology of the studied areas, through karst processes (where the mountain ranges consist predominantly of limestone and dolomite) and differential erosion processes, enhanced by the high variability of rocky outcrops, due to both erosional and tectonic processes (Neri and Gianolla, 2007). Yet, the main parent materials outcropping in the six areas can be divided into four main lithological domains (Sartori et al., 2005; Neri and Gianolla, 2007):

* areas of calcareous rocks highly resistant to erosion;

* areas of siliceous metamorphic and volcanic and sandstones which can vary from resistant to moderately resistant to erosion;

* areas of outcrops of marls, conglomerates and sandstones which can vary from moderately to poorly resistant to erosion;

* areas of recent (Plio-Pleistocene and Holocene) deposits; glacial, alluvial and colluvial materials, which are composed exclusively of calcareous or siliceous lithotypes, or of a mixture of them, with different degrees of heterogeneity (Corsini et al., 2001).

Some of the study areas (e.g. Cortina) also show important examples of different types of ancient and active landslides (collapse, overturning, sliding), which have a primary role in the morphological evolution of the landscape (Neri and Gianolla, 2007), powerfully affecting the main course of the principal streams that cross the region (Corsini et al., 2001).

Past and present climatic conditions also contribute to landscape evolution in the

Dolomites areas. In particular, Quaternary glaciers, and fluvioglacial systems connected with them, were responsible for typical morphologies related to both erosion processes, as glacial cirques and hanging valleys, and depositional forms such as front and lateral moraines, and alluvial terraces (Corsini et al., 2000; Soldati et al., 2004). Therefore, the resulting landforms are strongly related to the activity of glaciers in the Late Pleistocene and Holocene (Corsini et al., 2001; Soldati et al., 2004), and their age can be estimated to be in the range between 16,000 and 12,000 years B.C. (Merkli et al., 2009). This relatively short geomorphologic evolution directly influences the age of the soils, which started to form after the Last Glacial Maximun (LGM) (Egli et al., 2008; Favilli et al., 2010).

2.2. CLIMATE

Depending on the distance from the North Adriatic Sea, the Dolomites can be divided into two different areas: the Internal and the External Dolomites (Pignatti, 1994). This distinction is due to the fact that humid winds coming from the Adriatic Sea, affecting the southern side of the Alps, produce fogs and intense rains. These present their maximum effects on the first peaks of Pre-Alps, diminishing little by little on the External Dolomites, while they hardly involve the internal ones, which present a drier climate. Consequently, the Internal Dolomites are characterized by a continental climate (maP= 1238 mm/year, maT= 6.2°C; rainfall is distributed with two peaks in spring and autumn) (Fig. 2a). The External Dolomites, instead, are characterized by a sub-oceanic climate (maP= 1422 mm/year, maT=5.2°C; rainfall is distributed during the months from April to November) (Fig. 2b). Nearly all the areas investigated are located within the Internal Dolomites, with the exception of Valzanca and Valsorda (in the Paneveggio-Pale di San Martino Regional Park), Val Visdende and the far south-eastern area of the territory of Cortina d’Ampezzo, which present the characteristics of the external ranges (Del Favero, 2001).

2.3 VEGETATION COVER

Relevant changes in the vegetation cover, in particular forests, are recorded in the two parts of the Dolomites range (Sburlino et al., 1999; Bini et al., 2002). In fact, the Internal Dolomites are dominated by coniferous stands composed of spruce, larch and Swiss pine (Pignatti, 1994), an arctic-alpine species residual from the Quaternary glaciations. The timberline, in the Internal Dolomites, rises up to 2400 m a.s.l. In the External Dolomites, in contrast, forests are composed of mixed softwood (spruce) and hardwood stands (beech), and the timberline is just at 1900 m a.s.l..

Pioneer communities of mountain pine (*Pinus mugo* Turra) are also quite widespread on rocky and not stabilized debris slopes, subjected to periodic landslides and avalanches. However, anthropic activity has broadly affected all the forests of the Eastern Alps, through the elimination of beech and silver fir in favour of spruce and pastures.

In the whole terrain examined, woods alternate with partly mown mountain meadows. As in the rest of the Alps, mown meadows are abandoned, rapidly disappearing ecosystems (Poldini and Bressan, 2007), and tend to turn into woods once more (Poldini and Oriolo, 1995). In numerous areas located above the timberline, at elevations between 2000 and 2500 m, vegetation is characterized by the dominance of pasture and shrubs. Marshlands, dominated by the typical vegetation of bogs with shallow water, are quite widespread in the investigated terrain, although of limited extent.

3. MATERIALS AND METHODS

3.1 SOIL SURVEY, ANALYSIS AND CLASSIFICATION

In the framework of studies carried out by our department on Alpine soils, since the 1997 a soil inventory was carried out in six selected areas of the Dolomites range. In each study area, investigation started with the interpretation of aerial photographs, and the identification of different landscape units. Afterwards, for each unit, representative soil profiles were described and sampled following the Italian guidelines (Costantini, 2007). The soil profiles were selected during an inventory giving an overview of the different soil types, their characteristics and variability in each area. Soil pits were dug from the topsoil down to the C horizon. A total of 225 sites were investigated.

All samples have been analyzed according to the procedures described by the manuals of the Italian Ministry of Agriculture and Forestry. Soil samples were air-dried and sieved to 2 mm. On the fine fraction the following parameters were determined: pH in water and in KCl (electrometric method described by Violante and Adamo (2000)), carbonates (gas-volumetric measurement by calcimetry, method described by Boero (2000)), organic carbon and organic matter (oxidation at the temperature of reaction method, described by Walkley and Black (1934) and by Sequi and De Nobili (2000), cation exchange capacity, total acidity, base saturation (Barium Chloride–Triethanolamine at pH 8.1 procedure, described by Gessa and Ciavatta (2000) and texture (pipette method preceded by destruction of organic matter pretreatment, described by Genevini et al. (1994)).

Climate data provided by ARPAV Meteorological Service Center in Teolo (PD) and referring to the period 1995-2004 have been used. For each selected site, data refer to stations located at altitudes both higher and lower than 2000 m a.s.l., in order to take into account the high altitudinal range of the investigated areas. Data on monthly temperatures and precipitations for the various areas have been elaborated with the Thornthwaite and Mather model (1957), modified by Armiraglio et al. (2003) to calculate the soil water balance.

Based on the water balance, soil moisture and temperature regimes have been defined according to the criteria of the latest edition of the American System of Soil Classification (Soil Survey Staff, 2010). All profiles described and analyzed from 1997 to 2009 were reclassified on the basis of reviewed soil temperature and moisture regimes, field observations and chemical and physical analyses.

3.2 STATISTICAL DESIGN

Multivariate techniques have been applied to investigate the influence of different environmental factors on soil geography in the Dolomites mountain area. The location of each observation was chosen randomly to sample different mountain ranges, elevation, topographic positions and substrates. The data set includes 210 soil profiles for which all the necessary pedological and environmental data were available. Data related to each profile comprise a total of 8 variables, both discrete and continuous. Five of them are local-scale environmental variables: elevation (meters above the sea level), exposure (in degrees: North (N) 0° = 360°), slope inclination (in percentage), parent material (6 classes) and vegetation cover (7 classes). The other three variables are related to soils: classification of soil (10 Suborders), total profile depth (centimeters), total number of horizons (Table 2).

Four continuous pedological and environmental data (total profile depth, exposure, slope and elevation) were analyzed by principal component analysis (PCA), while multiple correspondence analysis (MCA) has been used for discrete variables (soil classification, vegetation cover, parent material, total number of horizons). A coinertia analysis of these two sets of data was then carried out according to the methods described by Dolédec and Chessel (1994). A permutation test (also called Monte-Carlo test, or randomization test) was used to assess the statistical significant correlation between the two data sets. All multivariate analyses were carried out by using the ADE-4 software package (Thioulouse et al., 1997).

3.3 MAP PROCESSING AND LAND EVALUATION

A conventional soil map (with the original scale of 1:50,000) was produced for each of the investigated areas to obtain more information about the soils of the region, and to increase the existing soil database (Costantini, 2007).

Soil maps and thematic maps derived from the previous ones were processed using GIS softwares (ArcView3.2; ArcGis 9.3). The thematic maps concerned the most significant aspects of the terrain investigated, namely soil erosion risk, forest land use and tourism impact. Derived maps were developed applying land evaluation methods for specific purposes (F.A.O., 1976; Calzolari et al., 2009). The current method, as reported by Calzolari et al. (2009), consists of attributing specific numerical values to selected pedological and environmental characters (e.g. profile depth, texture, pH, base saturation, bulk density, slope inclination, depth to groundwater, etc.), which may constitute a limitation for a given land use of the various land units. The number of the selected characters may change depending on the land use under consideration. The values attributed to single characters of each land unit are subdivided in classes; their summation is compared with the values of the classes of the system utilized. The comparison between the resulting value of all characters and the classes (usually four) defined by the method, allows attributing each land unit to a specific class: for example, very suitable (S1), moderately suitable (S2), scarcely suitable (S3), or not suitable (N) class of the selected utilization.

To evaluate the soil erosion risk of the examined area, the original CORINE model formulation (Briggs et al., 1989) has been modified by introducing a geological factor, besides the land components usually considered (climate, soils, topography, land cover), in order to take into account the heterogeneous lithological composition of rock outcrops in the Dolomites. Considering the terrain to be highly prone to erosion, to the four risk classes suggested by the original CORINE method a fifth class (very high risk) was added. Once estimated the various factors involved in erosion phenomena (climate, geology, soil, topography), the PSER (Potential Soil Erosion Risk) was calculated as follows:

PSER = soil erodibility * rain erosivity * slope index.

The Potential Soil Erosion Risk refers to a low land cover and a low level of protection practices, and it is expressed by four classes of increasing potential risk, from 1 (no PSER) to 4 (high PSER).

The summation of the land cover effect to the PSER evaluation allows estimating the *actual* soil erosion risk (ASER), as expressed by five classes of increasing risk (from absent to very high risk).

Land suitability for forestry was evaluated applying the method proposed by Bartelli (1978). This method involves attributing numerical estimates to twelve characters considered the most important for their influence on forest productivity, namely: soil depth, texture, stoniness (field estimate), permeability, available water capacity calculated following Armiraglio et al. (2003), drainage, pH, cation exchange capacity (laboratory determinations), wood species, dominant tree height (field estimate), slope, erosion risk. For the purposes of this research, the method was modified adding the parameter "environmental risk", which accounts for the risk of flooding or landslides, to the twelve characters considered the original method. For each character, scores range from 1 for the most favourable cases to 10 for the worst situation. Scores for "erosion" character were assigned using the results of soil erosion risk assessment of the land produced by the CORINE method, described above. Concerning the wood species to be considered, only species well adapted to local climatic and pedological conditions were selected, according to Giordano (2002) suggestions: *Picea excelsa* (Lam.) Link, *Pinus cembra* L., *Larix decidua*, Mill., *Pinus mugo* Turra and *Pinus sylvestris* L..

Finally, for evaluating the land suitability for tourism, the methodology developed by Massidda and Puddu (1997) has been applied. According to these authors, the assessment of land suitability for tourism was carried out considering thirteen environmental and pedological characters, assigning them different scores, similarly to what was previously described for forest suitability evaluation. The selected characters are divided into three different groups related to:

- *resources*, defined as land characteristics which can be attractive from the touristic point of view (soil typology included);
- *management*, including characteristics which express *how* resources are proposed

and developed for tourist services;

- c*onservation*, defined as the sum of characteristics, which define land vulnerability (soil features included).

The allocation of units to different suitability classes is done by assigning a score according to a sliding scale from 10, for the best condition, to 1, for the worst one. As the use of a parametric evaluation method may involve a subjective approach in assessing the weight to be given to each characteristic, the technique of scoring must be such as to minimize this subjectivity. Therefore, values assigned to each item are converted to ten percent (e.g. 4 becomes 40% = 0.4) and then:

- a simple arithmetic average of the estimates attributed to *resources* characters for each land unit is calculated;
- a lowered average of the estimates attributed to *management* characters for each land unit is calculated, counting the lowest score for three times before calculating the average;
- a lowered average of the estimates attributed to *conservation* requirements for each land unit is calculated, counting all the data with a score lower than 4 three times before calculating the average.

The summation of these three average values calculated for each land unit results in a single numeric value, which allows attributing the land unit to the specific class of suitability for tourism.

4. RESULTS

4.1 *PEDOGENIC ENVIRONMENT*

The USDA Soil Taxonomy system provides a classification of soil types into four pedogenic categories: Order, Suborder, Great Group, Subgroup (Soil Survey Staff, 2010).

Orders group those soils have or have not specific diagnostic horizons, as an expression of pedogenic factors responsible for soil formation.

Suborders comprehend soils, within each *Order*, subdivided according to soil moisture regimes, parent material and other characters.

Great Groups include soils of previous categories with specific properties (e.g. texture, base saturation, colour, mottles, duripan, etc.).

Subgroups indicate steps (intergrades) to other major groups.

In the investigated area, a total of 5 orders, 11 suborders, 17 groups and 38 subgroups have been identified (Table 3). Nomenclature follows Latin or Greek roots, with some exceptions. In particular, the soil Orders identified are:

**Entisols*: recent soils that do not show any profile development other than a surface horizon (A horizon) over the parent material.

**Inceptisols*: soils that form quickly through weathering of parent material; they are more developed than Entisols and have a mineral subsurface B horizon, resulting from *in situ* physical alterations and chemical transformations *(cambic* horizon).

**Mollisols*: soils that have a deep blackish surface horizon (*mollic* epipedon), resulting from long-term accumulation of organic materials. Their parent material is typically base-rich and calcareous.

**Spodosols*: soils that have a subsurface B horizon (*spodic* horizon), enriched in humic acids, iron and Al-oxyhydroxides.

**Histosols*: soils that consist primarily of organic materials.

Lower taxonomic categories reported in Table 3 indicate differences in soil moisture, depth, base saturation and other specific properties of investigated soils.

Field observations allowed identifying different pedogenic environments at selected sites, based on different lithology, morphology, climate and vegetation cover. Specifically, the upper parts of the main mountain ranges, located at altitudes above 2000 m a.s.l., have been distinguished from those located at lower elevations, characterized by different soil temperature regimes. More particularly, in the upper areas, extending up to 3000 m a.s.l., soils are characterized by *cryic* temperature regime (mean annual soil temperature between 0 and 8 °C , without permafrost) and *perudic* moisture regime (rainfall exceeds evapotranspiration during all months of normal years) (Soil Survey Staff, 2010). Since these areas are located, for the most part, above the tree line, their vegetation cover consists mainly of alpine grasslands and meadows and, at lower elevation, mountain pine or alder, rhododendron and sparse coniferous stands.

Conversely, in the areas located at lower altitudes, between 800 m and 2000 m a.s.l., soils are characterized by *frigid* temperature regime (mean annual temperature between 0 and 8 °C, with a difference between mean summer and mean winter soil temperature of 6 °C or more) or *mesic* (mean annual soil temperature between 8 °C and 15 °C) and *udic* (soil moisture control section not dry in any part for as long as 90 cumulative days in normal years) or *perudic* moisture regime (Soil Survey Staff, 2010). The vegetation of these areas consists mainly of forests composed of spruce, Swiss pine and silver fir; these forests are replaced by pasture where slopes are gentle, and by mountain pine where slopes are more unstable and steep.

Moreover, two main lithological domains have been distinguished at altitudes both higher and lower than 2000 m a.s.l.: mainly calcareous lithotypes (dolomite, limestone, calcareous debris, marls) and siliceous lithotypes (sandstones, metamorphic and volcanic rocks and debris). Soils developed from these two different lithotypes show very different features and properties, varying from sub-alkaline to strongly acidic in reaction, from base saturated to unsaturated, from carbonate-rich to completely lacking, etc. Mixed debris creates a sort of continuity between the two lithological domains described above.

The flow diagram in Fig. 3 shows the soil evolution from different parent materials at altitude both higher and lower than 2000 m a.s.l.. Specifically:

- soils at the earliest stages of evolution from mixed debris (in the centre);
- soils from calcareous parent material (on the left);
- soils from siliceous parent material (on the right);
- wetlands soils (at bottom).

4.2 *STATISTICAL ANALYSIS*

The results of the coinertia analysis indicate that the set of variables explained 60% and 22% of pedological variability along axes 1 and 2, respectively. The co-structure between the two data sets was significant, as indicated by Monte-Carlo permutation test (0.147 P=0.001).

The graphs in Figure 4 show:

- the factor loadings, i.e. the correlation between the experimental variables and the factors extracted by the Principal Component Analysis (PCA) (ranging between – 1, + 1) (Fig. 4 above);
- the scores calculated by the application of the Multiple Correspondence Analysis (MCA) (ranging between - ∞, + ∞) in the coinertia plane (Fig. 4 below).

The two plots are different, due to graphical reasons, but they have to be interpreted simultaneously as the projection plane is the same. Data interpretation needs to keep in mind the basic rules of the multivariate analysis. For example, the variables “total soil depth” and “elevation” have a high weight in the PCA and are independent each other. In the coinertia plane these variables are located in the IV and I quadrants, respectively. In the same quadrants of the coinertia plane the qualitative variables “coniferous forests” (IV quadrant) and “grasslands” (I quadrant) occur. This indicates that these two different kinds of vegetation cover are linked to total soil depth and to the elevation, respectively (i.e. coniferous forests are related to deep soils, grasslands only to high elevation, irrespective of the soil depth).

Therefore, as shown in Figure 4 (top), the first axis of variation is indicative of a temperature gradient driven by elevation. The second axis of variation corresponds primarily to the total profiles depth, influenced by morphological factors, especially slope.

The results revealed that the parameter “exposure” is not related to any other parameter. In contrast, elevation is correlated with most of the parameters (total soil depth, kind of vegetation, parent material, total number of horizons) (Fig. 4, bottom). In particular, total soil depth decreases when elevation increases, being elevation negatively correlated with soil depth. At the same time, the total number of horizons of each profile increases with total soil depth (H7) (positive correlation) and decreases (H1) when elevation is higher (negative correlation). Despite this, profiles with a high number of horizons are also positively correlated with high elevation (H7).

With regard to vegetation cover, grasslands, pastures and shrubs show a positive correlation along the first coinertia axis. Coniferous forests, mixed forests and meadows, in contrast, show a negative correlation along the same axis. Mixed forests, together with wet meadows, are also negatively correlated along the second axis and, consequently, with the total soil profile depth.

Concerning the parent material, calcareous rocks show both a positive correlation along the first coinertia axis, and a negative correlation along the second one. Other sedimentary rocks (marlstones, conglomerates and sandstones) show a clear positive correlation along the second axis, while unconsolidated material (debris) show, in general, a correlation along the first axis. While calcareous, arenaceous and mixed debris are negatively related with the first axis, siliceous debris is positively correlated along it.

Suborders of the American Soil Classification System also show some interesting correlations along the coinertia axes. Cryods (Subord5) show a clear positive correlation along the first axis, while Cryepts (Subord4), conversely, show a clear positive correlation along both. Udolls (Subord10) show a high positive correlation along the second axis as, to a lesser extent, Saprists (Subord8) and Orthods (Subord7). Orthents (Subord3) or Rendolls (Subord2) appear positively and negatively correlated, respectively, only along the first axis.

Orthents and Cryepts show a positive correlation both with calcareous and siliceous rocks, while Cryods, Humods and Orthods (Subord5, 6 and 7) are correlated only with siliceous parent material. Rendolls seem to be more correlated with calcareous or mixed debris than with carbonate rocks.

Finally, soils showing a correlation along the first axis show also a correlation with specific types of vegetation cover: Orthents, Cryepts, Cryods, Humods and Orthods are clearly correlated with grassland, pastures and shrubs, while Rendolls are correlated especially with meadows and mixed forests.

4.3 LAND EVALUATION FOR SPECIFIC PURPOSES - Cortina d'Ampezzo valley case study

Current methods of land classification (F.A.O., 1976; Calzolari et al., 2009) for specific purposes were applied to the investigated areas, in order to derive maps to be used in land planning. The following maps were derived from the soil map: Soil Erosion Risk, Land Suitability for Forestry and Land Suitability for Tourism. Full information on processed maps is available in Bini et al. (2008) and Zilioli and Bini (2009a). As an example of application, the case of Cortina d'Ampezzo territory is reported. The soil map of the whole valley, composed of 24 cartographic units (Table 4), has been processed in order to derive thematic maps.

Since the Cortina territory is affected by erosion and intense morphological dynamics, attention was focused primarily on the soil erosion risk assessment. The CORINE procedure allowed subdivision of the land into 5 classes of increasing risk (Fig. 5).

- Extremely high erosion risk
- High erosion risk
- Moderate erosion risk
- Low erosion risk
- No erosion risk

The evaluation showed that great part of the terrain (50%) is affected by moderate erosion risk (Table 5), with 21% affected by extremely high risk, in areas with random vegetation cover on loose colluvial materials and steep morphology.

The units 6, 7, 9-11, 14-19 in Table 4 have been classified as subjected to moderate or high soil erosion risk, due to the absence of a continuous vegetation cover and to the presence of steep slope, but also to shallow soils. Also the units 20 and 21, with soils developed from marly and clayey debris, showing liquefaction phenomena present moderate soil erosion risk.

The low erosion risk class is composed of five units (8, 12, 13, 22 and 23 in Table 4), characterized by gentle slopes, deep soils, and continuous vegetation cover.

The only unit in the class where soil erosion risk does not occur, is the unit 24, characterized by continuous vegetation cover, deep soils, and concave topography.

A second land classification of the same territory was undertaken to evaluate its suitability for forestry. The map resulting from the evaluation procedure, as shown in Figure 6, subdivides the land into five items:

- S1: very suitable areas
- S2s: moderately suitable areas (soil properties restrictions indicated by the letter “s”)
- S3sc: scarcely suitable areas (soil properties and climate restrictions indicated by the letters “s” and “c”)
- N: not suitable areas
- NR: not detected areas

Land suitability for forestry evaluation showed a terrain predominantly not suitable or poorly suitable to wood production (Table 5) because of extensive areas located at elevation higher than the timberline, on steep slopes and very shallow soils (units 2-7, 9-11, 13, 14 and 16 in Table 4).

Some areas resulted not suitable also because of the high flooding and landsliding risk (units 20 and 21). Approximately one third of the land, however, presents a good suitability for forestry (units 8, 12, 15, 17-19, 22-24 in Table 4), even if partly limited by unfavorable soil properties (mainly shallow soils with low AWC) and topographic factors (slopes from moderately to very steep slopes).

Finally, a land suitability evaluation for tourism has been carried out. According to the procedure suggested by Massidda and Puddu (1997), the investigated terrain has been divided into four classes:

- S1: Very suitable
- S2: Moderately suitable
- S3: Scarcely suitable
- N: Not suitable

The results, shown in the *Land Suitability for Mass Tourism Map* (Fig. 7), indicate a very low suitability of the land to tourism (Table 5), with restrictions due to the fact that the same aspects that make this terrain very attractive from a touristic point of view, are also those that make it particularly vulnerable to an excessive anthropic pressure, as strong seasonal tourist fluxes.

Eleven units (unit 24 and units 2-17 in Table 4) resulted not suitable for mass tourism, because of very severe limitations due to high elevation, to difficult accessibility and the presence of shallow soils prone the erosion (see Fig 5).

Only four of the remaining units resulted very suitable to mass tourism (units from 20 to 23 in Table 4), while the other three (units 1, 18 and 19) were classified as moderately suitable because, although not particularly vulnerable to anthropic pressures, they resulted not very attractive from the touristic point of view.

5. DISCUSSION

5.1 *QUALITATIVE MODEL OF SOIL EVOLUTION*

Information provided by field observations and statistical analysis allowed us to develop the qualitative model of soil evolution in the Dolomites environment shown in Figure 3. The distribution of soil orders in the study area is mainly consistent with climate, with parent material and with landform stability, as reported for other alpine regions (Sartori et al., 1997; Previtali, 2002). Conversely, in the Dolomites region the vegetation cover does not appear to be an important soil forming factor, as also highlighted for other mountain regions (Briggs et al., 2006).

Calcareous lithology has a typically hard-brittle behavior that leads, in the investigated area, to the formation of steep ridges. As an example of soil distribution in calcareous environments, a cross-section on calcareous parent material is shown in Figure 8. The upper part of calcareous reliefs is characterized by rock outcrops and extensive glacial or slope deposits. At higher altitudes (above 2000 m) and with steep morphology (> 35°), therefore, the soil cover is often discontinuous. Soils that characterize the sites with greater erodibility (depending on slope and on parent material consistency) are frequently poorly developed (*Udorthents* or *Cryorthents*), thin (from *Lithic* to *Typic*), rich in skeleton (mineral particles > 2 mm in size), with a coarse texture, sub-alkaline to alkaline (Previtali, 2002).

The same is true at lower altitudes, on very steep slopes, partly colonized by pioneer vegetation, where the prevailing parent material is calcareous glacial deposits.

An increase in soil thickness corresponds to decreasing slope (Sartori et al., 2005). On structural gently sloping surfaces (< 35°), under continuous vegetation cover and a high rate of organic matter production, soil evolution may proceed through *Mollisols* (*Cryrendolls* and *Haplocryolls* or *Haprendolls* depending on altitude), up to *Inceptisols* (*Eutrudepts* or *Eutrocryepts*) (Previtali, 2002).

The formation of *Mollisols*, depending on slope, depth and profile differentiation (*Lithic*/*Typic Cryrendolls* and *Lithic*/ *Typic*/*Inceptic Haprendolls*), is particularly influenced by organic matter which has the role to trigger the formation of very stable organic-mineral complexes, with the consequent formation of soils with a very dark and rich in bases surface horizon. These soils are characterized by a sub-alkaline or alkaline pH and are moderately deep and rich in coarse particles. They represent only a small percentage of investigated soils (Table 3) because, under heavy rainfalls and rapid drainage, as observed also by Egli and Fitze (2001), they are subjected to a faster decomposition of the organic matter and to intense leaching phenomena, which involve a partial desaturation of the profile, with consequent pH decrease, carbonate removal and transition from a *mollic* epipedon to an *umbric* one. As a consequence, deep brown soils with a *cambic* horizon develop, with a pH from sub-alkaline to neutral. These soils, especially at lower altitudes, are the most common soils in the calcareous environment, on glacial deposits or on recent fluvial terraces, under continuous forestry vegetation cover (Neri and Giannolla, 2007). In some cases, desaturation processes can be so intense to lead to leached and decarbonated brown soils. The different degree of desaturation and development of these soils is reflected in the various subgroups (*Typic Haplocryepts* and *Humicryepts* or *Lithic / Typic / Rendollic / Dystric Eutrudepts* (Sartori et al., 1997).

On siliceous parent material, the high erodibility of the rocks creates a subrounded gentle morphology, with average slopes less than those of calcareous environments. As an example of soil distribution in siliceous environments, a cross-section on siliceous parent material is shown in Figure 9. The upper part of siliceous relieves is characterized by rock outcrops and extensive glacial or slope deposits (Previtali, 2002). At higher altitudes (above 2000 m), at sites characterized by high instability due to severe slope or to erosion phenomena caused by overgrazing, the soil cover is often discontinuous and poorly developed soils are widespread, under pioneer vegetation or pastures. These soils are shallow, rich in coarse mineral particles and poorly differentiated, with a pH from subacid to acid (acid *Udorthents* and *Cryorthents*). The subgroups in which they are subdivided vary mainly as a function of the slope, the profile depth and the substrate typology (*Lithic*/*Typic Udorthents* and *Cryorthents*).

In siliceous environments, soil evolution follows the typical sequence of desaturated soils (Sburlino et al., 1999; Previtali, 2002), which consists in the further development of brown soils on mixed debris, neutral to subacid and partially desaturated (*Humicryepts* and *Haplocryepts* or *Eutrudepts*), and more acidic brown soils on exclusively siliceous materials (*Dystrocryepts* and *Dystrudepts*).

In all cases these soils are moderately deep, with a greater differentiation of the profile than in the previous cases, and with a *cambic* horizon; especially at lower altitude, these soils are the most common on siliceous environments, on moderately steep stable slopes (Sartori et al., 2005).

Only a small fraction of the investigated soils, developed in areas of greater stability (usually on gentle slope deposits), under continuous vegetation cover (in particular coniferous stands or acidophylous pastures), at elevations over 1500 m a.s.l., shows a further stage of development, with a higher profile differentiation. In these areas, in particular on north-facing sites, characterized by lower temperature, lower evapotranspiration and higher moisture, the degree of chemical weathering increases (Egli et al., 2006).

These are the podzolic soils, moderately deep, in which podzolization processes may have been, in some cases, weak (*Spodic Dystrudepts*), in other cases rather intense (*Haplocryods* and *Placocryods* or *Haplorthods* and *Haplohumods* according to the elevation). The different degree of development of the profiles, based on local intensity of translocation processes (Lundström et al., 2000), is expressed by the various subgroups in which these soils are subdivided (*Entic*/*Typic Haplocryods* and *Placocryods* or *Lithic*/*Entic*/*Typic Haplorthods* and *Haplohumods*).

The Dolomites are rich in water-saturated wetlands areas, in which the changing level of groundwater controls soil evolution from types with high content of undecomposed organic matter (*Hydric Haplofibrists*, *Hydric/Fluvaquentic Haplohemists* and *Typic Haplosaprists*), to more mineralized soil typologies (*Typic Endoaquents*, *Aquic Udorthents* and *Aquic/Aquic Dystric Eutrudepts*). Morphologically, these wetland areas coincide, at higher elevation, with glacial and karst basins or tectonic depressions. At lower elevation, however, they are located between counterslopes generated by landslides bodies involving poorly permeable geological formations (Neri and Giannolla, 2007).

All comments reported in this paragraph are summarized into the flow diagram in Figure 3.

5.2 *RELATIONSHIPS BETWEEN ENVIRONMENTAL AND PEDOLOGICAL PARAMETERS*

Results of statistical analysis show that total soil depth decreases when elevation increases, elevation being negatively correlated with soil depth. This is due to the worsening of climatic conditions: at high elevation the soil temperature regime changes to *cryic* conditions, and pedogenic processes are slowed down (Legros, 1992; Bockheim and Koerner, 1997). At the same time, the total number of horizons of each profile decreases when elevation is higher and increases with total soil depth. Despite this, the results show also that the profiles with a high number of horizons are correlated with high elevation and this is probably due to a very variable slope factor in the alpine environment. Irrespective of elevation, geomorphologic conditions can change from stable concave sites to highly unstable convex surfaces. (Zilocchi, 2003). With regard to vegetation cover, grasslands, pastures and shrubs, showing a positive correlation along the first coinertia axis, confirm their abundance, for climatic reasons, at higher elevations. The climate also affects the distribution of coniferous and mixed forests in the subalpine belt at lower elevation, as shown by their negative correlation along the same axis. Also meadows show this negative correlation along the first axis, and this is probably due to their dependency on traditional mowing activities, which are concentrated at lower elevations (Bini et al., 2008).

Mixed forests, together with wet meadows, are also negatively correlated along the second axis and, consequently, with the total soil profile depth, showing that these two kinds of vegetation cover, are influenced by both elevation and soil depth, growing on shallower soils than the other types of vegetation.

Concerning the parent material, results strongly support the theory that pedogenesis in this environment involves *in situ* bedrock weathering, as reported also for other alpine regions (Munroe et al., 2007).

Results show that calcareous rocks (primarily dolostones and limestones) outcrop at higher elevations and, being more resistant to erosion than other sedimentary rocks, prevent, together with the extreme climatic conditions, the development of deep soils. Other sedimentary rocks (marls, conglomerates and sandstones) show a clear positive correlation along the second axis and this is due to their low resistance to chemical and physical alteration processes, which enhance soil deepening. Unconsolidated materials (debris) show, in general, a correlation along the first axis. In particular, siliceous debris is positively correlated along it and this is due to the outcropping of siliceous parent material and, consequently, to the debris produced by its alteration, predominantly at higher elevation (Zilioli and Bini, 2009b).

As described above, Suborders of the American Soil Classification System (Soil Survey Staff, 2010) also show some interesting correlations along the coinertia axes. In particular, while Cryods (Subord5), showing a clear positive correlation along the first axis, are distributed predominantly at higher elevations, Cryepts (Subord4), conversely, show a clear positive correlation along both axes, becoming shallower when the elevation increases. Udolls (Subord10) and, to a lesser extent, Saprists (Subord8) and Orthods (Subord7), showing a high positive correlation along the second axis, indicate their major correlation with morphologic factors, with an increase of total soil depth and total horizons number, compared to other less developed soils as Orthents (Subord3) or Rendolls (Subord2). These two suborders are positively and negatively correlated, respectively, only along the first axis and this is due to the fact that they are predominantly influenced by the temperature gradient, with Mollisols widespread at lower elevations and Entisols at higher elevation, where pedogenic processes are slower. Orthents and Cryepts show also a positive correlation both with calcareous and siliceous rocks, confirming their distribution on both these kinds of parent materials, while Cryods, Humods and Orthods (Subord5, 6 e 7), as expected, are distributed only on siliceous rocks or debris (Zilioli and Bini, 2009b). Finally, the profiles show also a correlation with specific types of vegetation cover. In fact, while Orthents, Cryepts, Cryods, Humods and Orthods are clearly distributed predominantly under grasslands, pastures and shrubs, Rendolls seem to be related especially with meadows and mixed forests.

5.3 CONSIDERATIONS ON LAND EVALUATION RESULTS - Cortina d'Ampezzo

valley case study

As reported above, results obtained by the evaluation of soil erosion risk point to a generally fragile terrain with little developed soil cover and marked erosion episodes, particularly due to the anthropic impact. The units that have been classified as areas with high soil erosion risk coincide for the most part with pasture and grasslands at higher elevations. Once exposed, thin soils distributed at high elevations, poorly developed and characterized by a coarse texture (*Udorthents* or *Cryorthents*) (Zilioli and Bini, 2009b), are very vulnerable and prone to erosion. In fact, at higher elevation, low temperature and frost, combined with steep morphology, mean that rehabilitation of vegetation cover is slow. The action of frost is particularly severe on alpine humus soils when they are not protected by snow cover in late autumn and after the thaw (Hitz et al., 2001).

A lot of ski resorts and, therefore, intense winter tourism activities are concentrated in these areas. A large number of actions to extend ski runs and to create new sports facilities are implemented here every year. Therefore, it is reasonable to expect important environmental impacts such as destruction of vegetation and removal of surface layers of the soil, resulting in further increases in soil erosion levels. The Falzarego Pass, located on the west side of Cortina valley, is an important example of such processes: here, during snow melting, it is possible to observe large areas devoid of vegetation and subjected to large soil losses (Bini et al., 2008).

Results of land evaluation for tourism also show a very low suitability to mass tourism of pastures and meadows located in the most elevated parts of the terrain. However, in these areas characterized by thin soils particularly prone to erosion, mass tourism is very intense, reaching a number of tourists which can rise up to 1,000,000 visitors every year, even if only for few months (Zilioli and Bini, 2009a).

Land suitability for forestry evaluation shows, furthermore, a terrain predominantly not suitable to wood production. Particularly interesting are the areas on which the city of Cortina d'Ampezzo extends, classified not suitable to moderately suitable for wood production because of their location on landslide bodies (Filippi, 1985; Soldati, 1999).

In fact, the Cortina valley shows examples of different types of active landslides, which have a primary role in the morphological and pedological evolution of the landscape (Soldati, 1999; Borgatti and Soldati, 2005). This is confirmed by a lot of soil profiles, showing a surface mantle of recently deposited material usually poorly developed (100-300 years; Filippi, 1985), covering a buried soil (mainly *Cryorthents* or *Eutrocryepts* on buried *Haplocryepts*) (Zilioli and Bini, 2009b).

Despite the low suitability for forestry, these areas are presently subjected to an important naturalization process, consisting of the development of secondary vegetation growth that has led to the progressive colonization by shrubs and trees, and then to the formation of a large forest (Conti and Fagarazzi, 2004, 2005).

The advancement of forest, in the last decades, on landslide areas around the urban area and close to human settlement, poses serious problems of slope stability, and therefore special attention is required in land planning. The soils of these units located on steep slopes and developed on marly and clayey debris, are particularly prone to liquefaction phenomena. The mobilization of blankets of soils particles and debris located around the urban area, in fact, could lead to a high risk not only for the environment but especially for population (Zilioli and Bini, 2009a).

By crossing the results of land evaluations for soil erosion risk, forestry and tourism (Table 4), it can be noticed that mapping units located around the urban area that are classified as not suitable for forestry, are also unsuitable for touristic land use; this is mainly due to the abandonment of traditional mountain activities abandonment and to the consequent secondary vegetation growth on the land mentioned above, making the landscape monotonous and diminishing its aesthetic value (MacDonald et al., 2000; Conti and Fagarazzi, 2004). It would be worthwhile, therefore, to suggest a different management of these units, not finalized to wood production, but rather, to the recovery of traditional activities aimed at the development of sustainable tourist land use, diminishing, at the same time, the high flux of tourists in areas at higher elevation, which are very interesting from the natural point of view, but also very vulnerable to excessive anthropogenic pressure, mainly because they are already subjected to a very high soil erosion risk (García-Ruiz et al., 1991). For these purposes, as highlighted also by McFee and Kelly (2005), the interaction of soil scientists and stakeholders groups is necessary for the development of sustainable management and research policy of forest soils and mountain ecosystems.

6. CONCLUSIONS

The data collected highlight the high environmental heterogeneity of the soils of the Dolomites. This heterogeneity can be explained with the considerable variability in the intensity of actions and interactions among different soil forming factors, and results in a wide range of soil typologies. Years of research in the Dolomites area, allowed us to understand better the different roles of environmental factors in the evolution of soils of this Alpine region. The importance of climate and parent material as soil forming factors emerges from the whole study. The reason can be found in the short time of soil formation due to the relative short historical geomorphology of

Dolomites, after the last glacial maximum (approx 12,000 y B.P.), and to the extreme environmental conditions under which soils develop. Although rainfall is intensive, temperature is rigid (*cryic* and *frigid* regimes), in particular in the higher part of the valleys, slowing down pedogenic processes. Moreover, steep slopes cause erosion problems and therefore soil rejuvenation acts against the formation of more developed soils, contributing to the formation of thin soils with a lithic contact within few centimetres. The importance of parent material is evident in soil development trends: the main trend is clearly divided into two sections, one of soils on siliceous rocks and one of soils on calcareous rocks. The first is more complex since, generally, soils on limestones, dolostones and marls are less developed than the others. This is due to the resistance of this kind of rock to weathering processes in the alpine environment. Statistical analyses, moreover, proved a useful tool to examine relationships between environmental and pedological variables, and to highlight soil evolution in relation to landforms.

Finally, land evaluation for specific purposes methods showed that the territory of Cortina d'Ampezzo is generally poorly suitable for the uses considered, with only few units (20, 21, 22, 23) classified as S1 for tourism and only one unit (17) highly suitable for forestry. Also significant is the fact that only five units (8, 12, 13, 22 23) present low soil erosion risk, suggesting that the terrain and the population are exposed to this important natural hazard.

Therefore, land evaluation results allowed us to identify some criticisms of the land management practices in the investigated areas (little developed soil cover and marked erosion episodes, forest advancement, negative impacts of tourism) and to suggest alternative land uses commensurate with to the potentiality of the terrain (e.g. traditional mowing and pastures), highlighting the fundamental contribution that the study of soils c can provide to natural resource conservation and the sustainable management of mountain ecosystems in the framework of UNESCO Dolomites World Heritage protection requirements.

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FIGURE CAPTIONS:

Fig. 1. Research area and selected sites in Trento and Belluno provinces (NE Italy): (1) Paneveggio-Pale S. Martino Regional Park, (2) Fassa valley, (3) Valfredda valley, (4) Gares valley, (5) Cortina d'Ampezzo territory, (6) Visdende valley.

Fig. 2. Ombrotermic diagrams showing average monthly temperatures (AMT) and rainfalls (AMP) in Internal (Cortina d'Ampezzo Station, on the top) and in External Dolomites (S. Martino di Castrozza Station, on the bottom) and corresponding average annual temperatures (AAT) and rainfalls (AAP) values.

Fig. 3. Flow diagram showing soil evolution in the Dolomites region from different parent materials, at elevations higher and lower than 2000 m a.s.l.. Left: soils on calcareous parent material; center: soils found on both the substrates; right: soils on siliceous parent material. Bottom: soils sequence in wetlands (from: Zilioli and Bini, 2009 b, *modified*).

Fig. 4. Coinertia analysis: plot of factor loadings of PCA analysis on coinertia plane (common plane) (above); plot of multiple correspondence coordinates on coinertia plane (common plane) (below).

Fig. 5. Cortina d'Ampezzo's Municipal Territory Soil Erosion Risk Map (reported scale ratio 1:150,000).

Fig. 6. Cortina d'Ampezzo's Municipal Territory Land Suitability for Forestry Map

(reported scale ratio 1:150,000).

Fig. 7. Cortina d’Ampezzo’s Municipal Territory Land Suitability for Mass Tourism Map (reported scale ratio 1:150,000).

Fig. 8. Cross-section on calcareous parent material: an example of soil distribution. Above the timberline poorly developed soils (*Cryrendolls* and *Cryorthents*) are widespread. At lower elevation an increase in soil thickness enhances profile development, forming *Haprendolls* and *Eutrudepts* on gently sloping landforms.

Fig. 9. Cross-section on siliceous parent material: an example of soil distribution. Above the timberline poorly developed soils (*Cryorthents*) are widespread. Podzolization processes occur in stable north-facing sites above 1500 m a.s.l.. In some cases they are weak, and brown soils (*Dystrocryepts* and *Dystrudepts*) are formed; in other cases they are rather intense, and podzols (*Haplocryods* and *Haplohumods*) are formed.

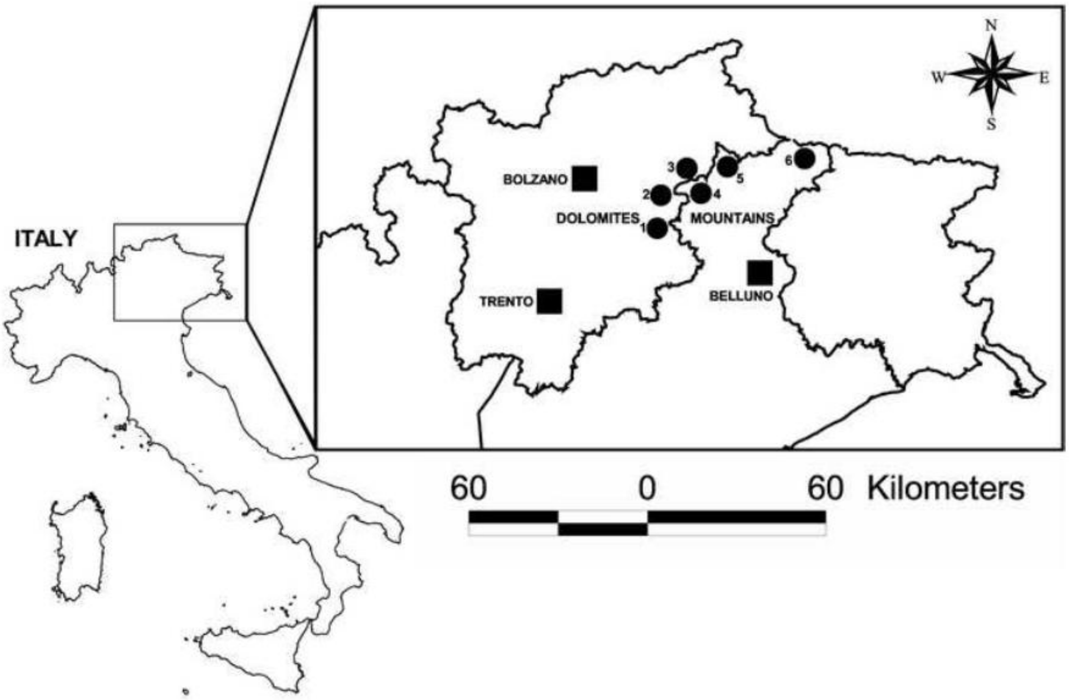
ITALY
N
W
E
S
BOLZANO
DOLOMITES
MOUNTAINS
TRENTO
BELLUNO
1
2
3
4
5
6
60
0
60
Kilometers

Fig. 1

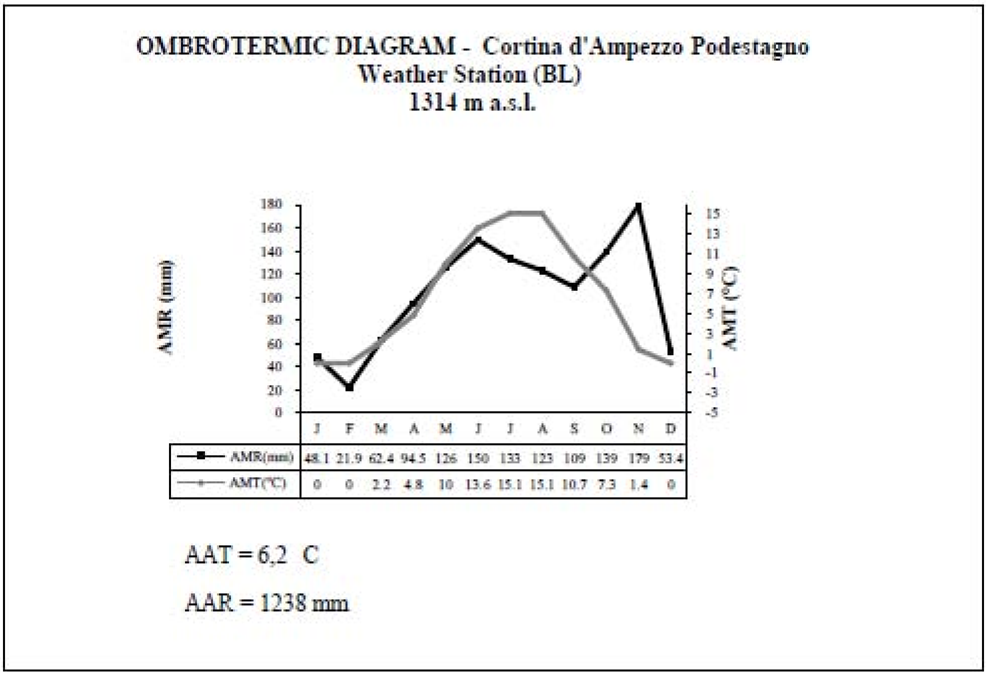
OMBROTERMIC DIAGRAM - Cortina d'Ampezzo Podestagno Weather Station (BL)
1314 m a.s.l.
AMR (mm)
AMT (°C)
180 160 140 120 100 80 60 40 20 0
15 13 11 9 7 5 3 1 -1 -3 -5
J F M A M J J A S O N D
AMR(mm) 48.1 21.9 62.4 94.5 126 150 133 123 109 139 179 53.4
AMT(°C) 0 0 2.2 4.8 10 13.6 15.1 15.1 10.7 7.3 1.4 0
AAT = 6,2 C
AAR = 1238 mm

Fig. 2. A

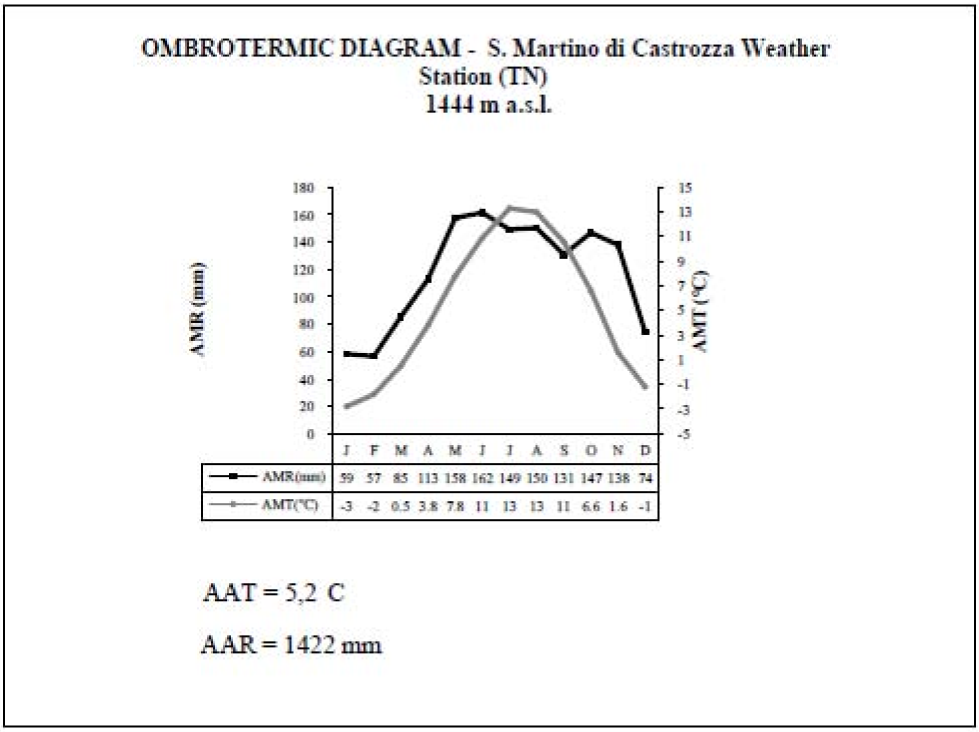
OMBROTERMIC DIAGRAM - S. Martino di Castrozza Weather Station (TN)
1444 m a.s.l.
AMR (mm)
AMT (°C)
180 160 140 120 100 80 60 40 20 0
15 13 11 9 7 5 3 1 -1 -3 -5
J F M A M J J A S O N D
AMR(mm) 59 57 85 113 158 162 149 150 131 147 138 74
AMT(°C) -3 -2 0.5 3.8 7.8 11 13 13 11 6.6 1.6 -1
AAT = 5,2 C
AAR = 1422 mm

Fig. 2. B

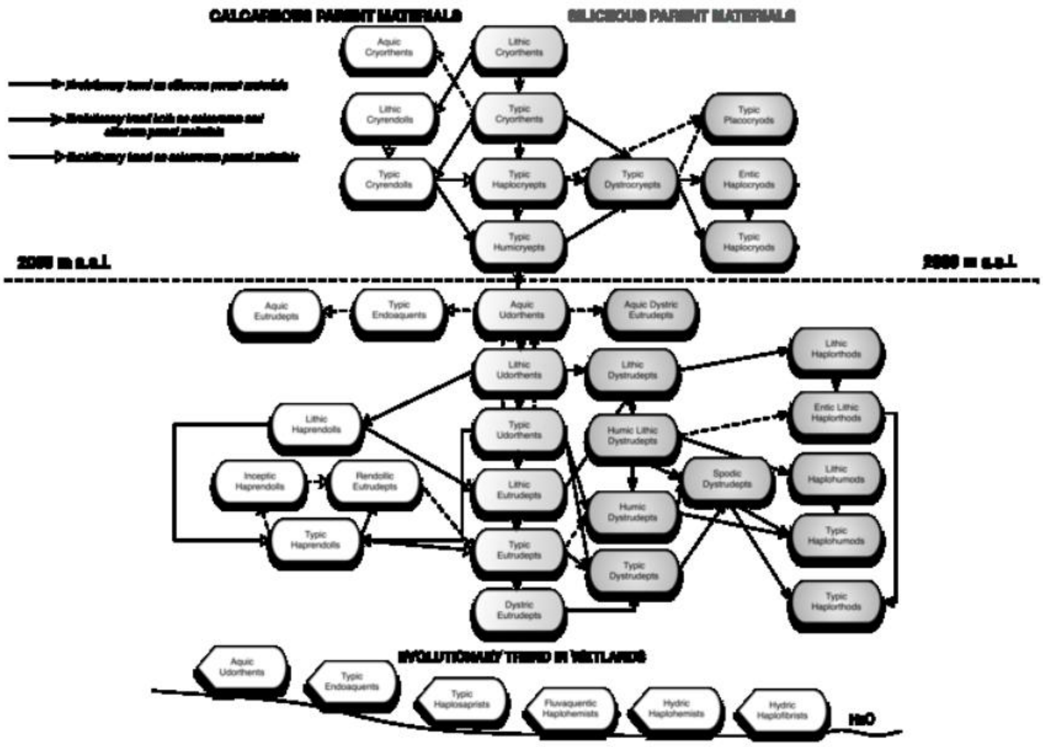
CALCAREOUS PARENT MATERIALS
SILICEOUS PARENT MATERIALS
Aquic Cryorthents
Lithic Cryorthents
Lithic Cryrendolls
Typic Cryorthents
Typic Placocryods
Typic Cryrendolls
Typic Haplocryepts
Typic Dystrocryepts
Entic Haplocryods
Typic Humicryepts
Typic Haplocryods
2000 m a.s.l.
2000 m a.s.l.
Aquic Eutrudepts
Typic Endoaquents
Aquic Udorthents
Aquic Dystric Eutrudepts
Lithic Haplorthods
Lithic Udorthents
Lithic Dystrudepts
Entic Lithic Haplorthods
Lithic Haprendolls
Typic Udorthents
Humic Lithic Dystrudepts
Inceptic Haprendolls
Rendollic Eutrudepts
Lithic Eutrudepts
Spodic Dystrudepts
Lithic Haplohumods
Humic Dystrudepts
Typic Haprendolls
Typic Eutrudepts
Typic Haplohumods
Typic Dystrudepts
Dystric Eutrudepts
Typic Haplorthods
EVOLUTIONARY TREND IN WETLANDS
Aquic Udorthents
Typic Endoaquents
Typic Haplosaprists
Fluvaquentic Haplohemists
Hydric Haplohemists
Hydric Haplofibrists
H2O

Fig. 3.

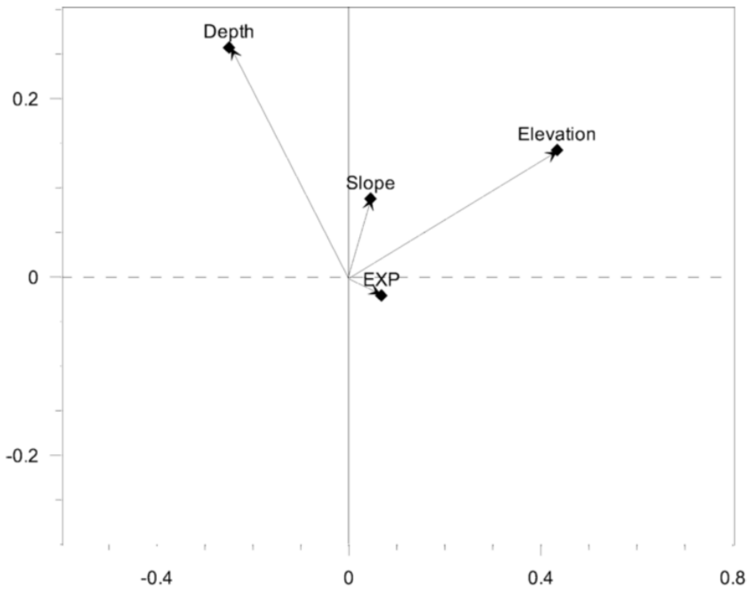

Fig. 4. Above

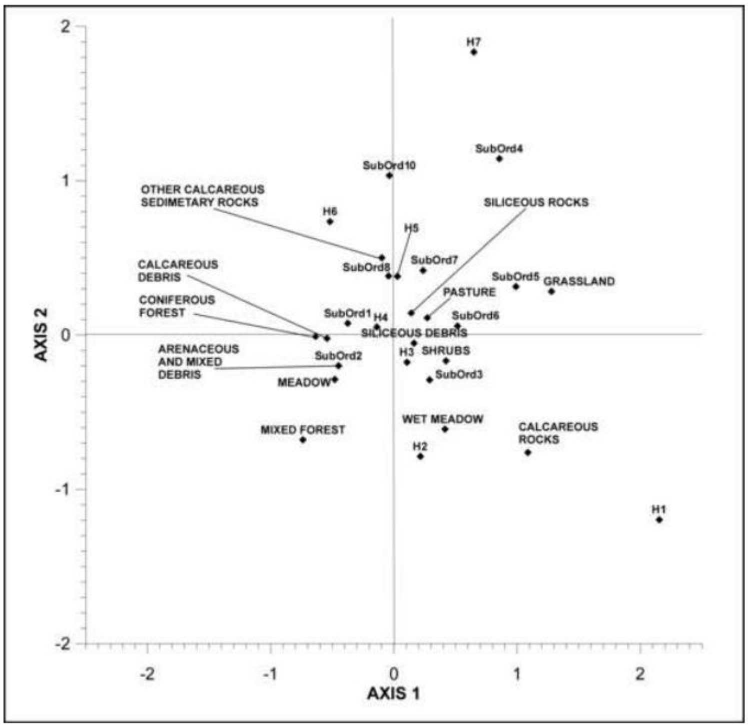

Fig. 4. Below

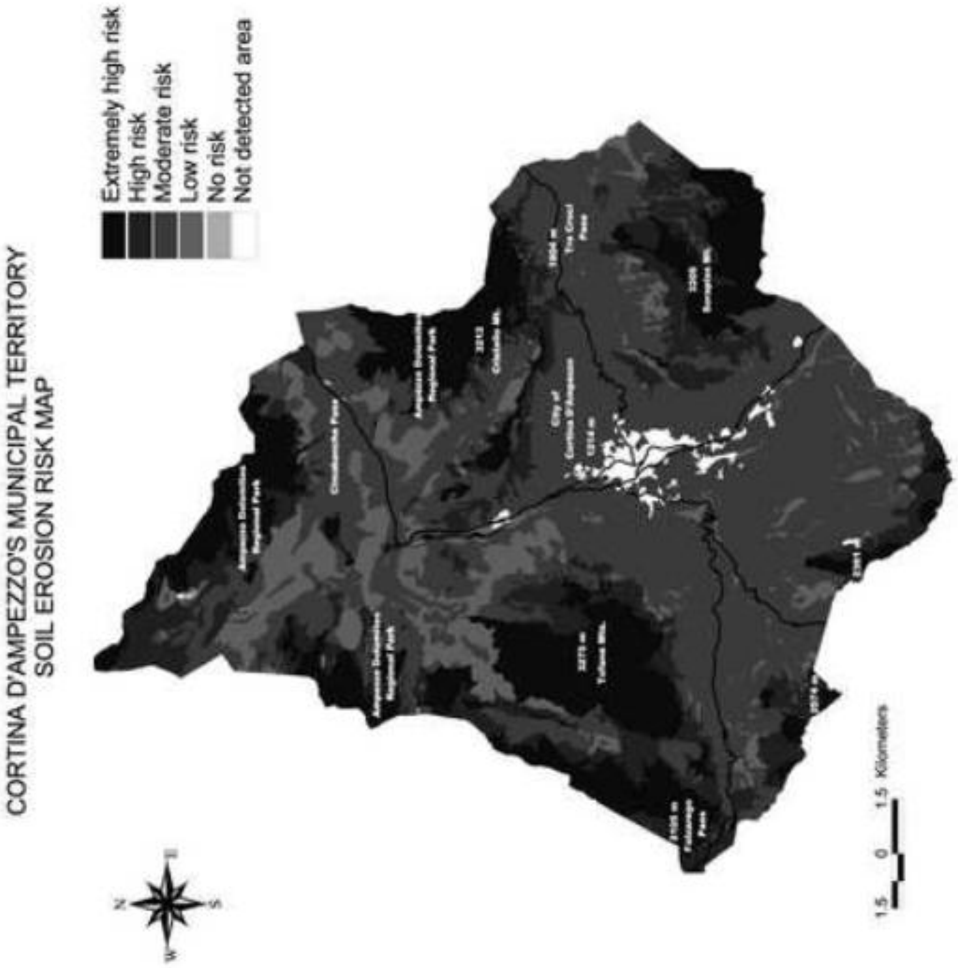
CORTINA D'AMPEZZO'S MUNICIPAL TERRITORY
SOIL EROSION RISK MAP
Extremely high risk
High risk
Moderate risk
Low risk
No risk
Not detected area
Ampezzo Dolomites Regional Park
Cimabanche Pass
Cristallo Mt.
Tre Croci Pass
Sorapiss Mt.
City of Cortina d'Ampezzo
Tofana Mt.
Falzarego Pass
N
S
E
W
1.5
0
1.5
Kilometers

Fig. 5

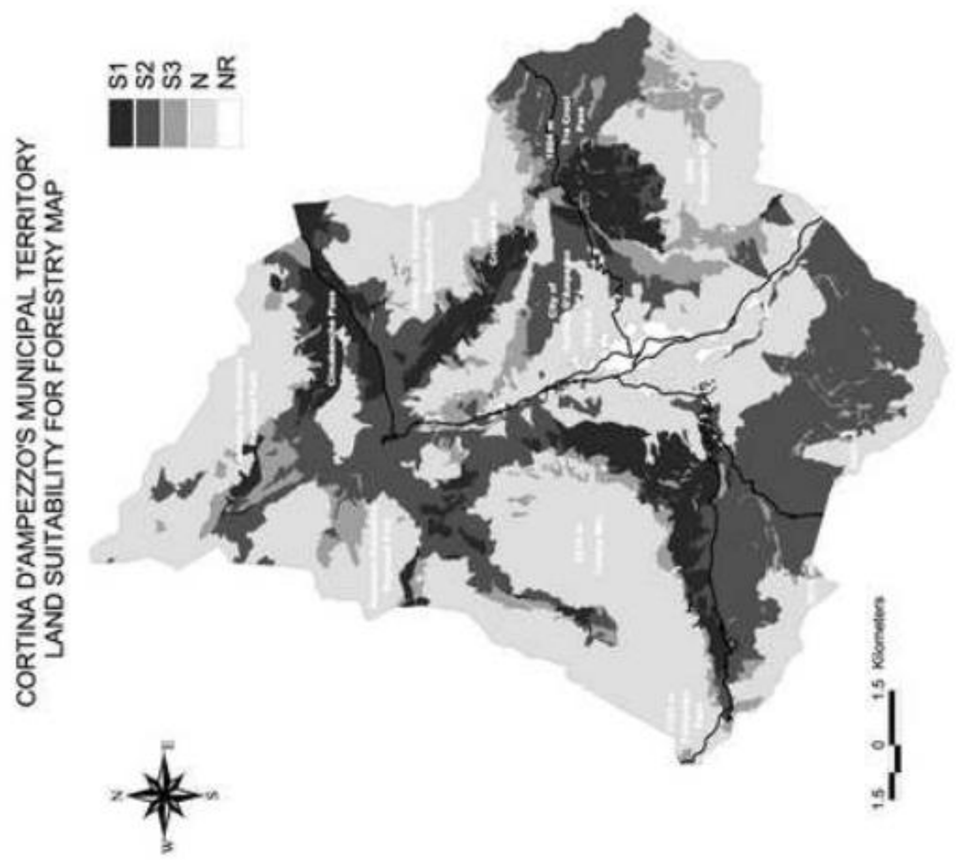
CORTINA D'AMPEZZO'S MUNICIPAL TERRITORY
LAND SUITABILITY FOR FORESTRY MAP
S1
S2
S3
N
NR
N
E
S
W
1.5
0
1.5
Kilometers

Fig. 6

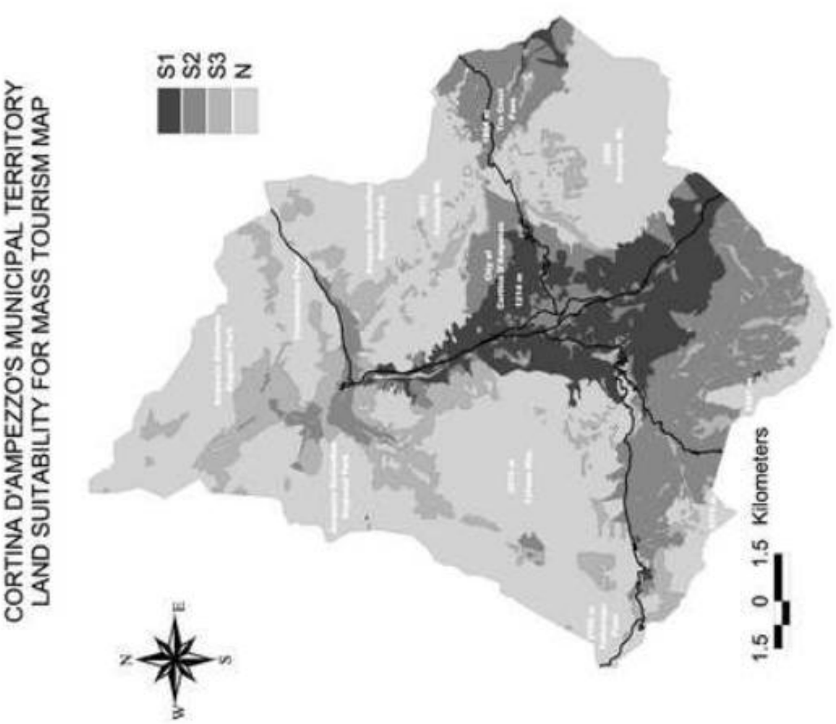
CORTINA D'AMPEZZO'S MUNICIPAL TERRITORY
LAND SUITABILITY FOR MASS TOURISM MAP
S1
S2
S3
N
1.5 0 1.5 Kilometers
N
E
S
W

Fig. 7

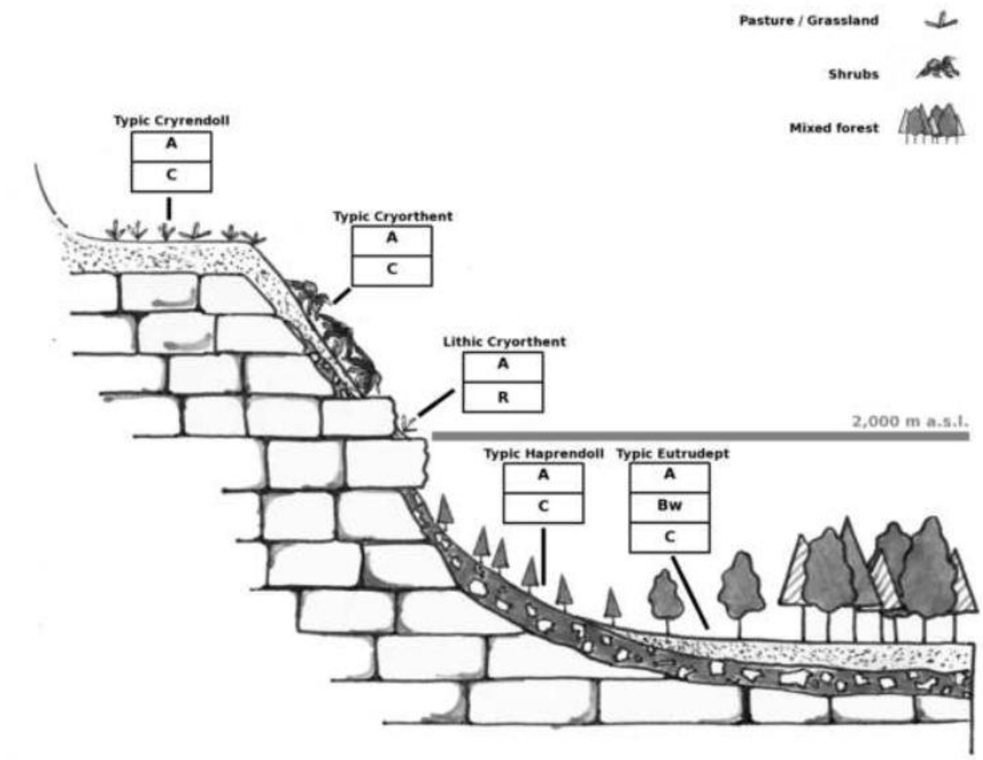
Pasture / Grassland
Shrubs
Mixed forest
Typic Cryrendoll
A
C
Typic Cryorthent
A
C
Lithic Cryorthent
A
R
2,000 m a.s.l.
Typic Haprendoll
A
C
Typic Eutrudept
A
Bw
C

Fig. 8

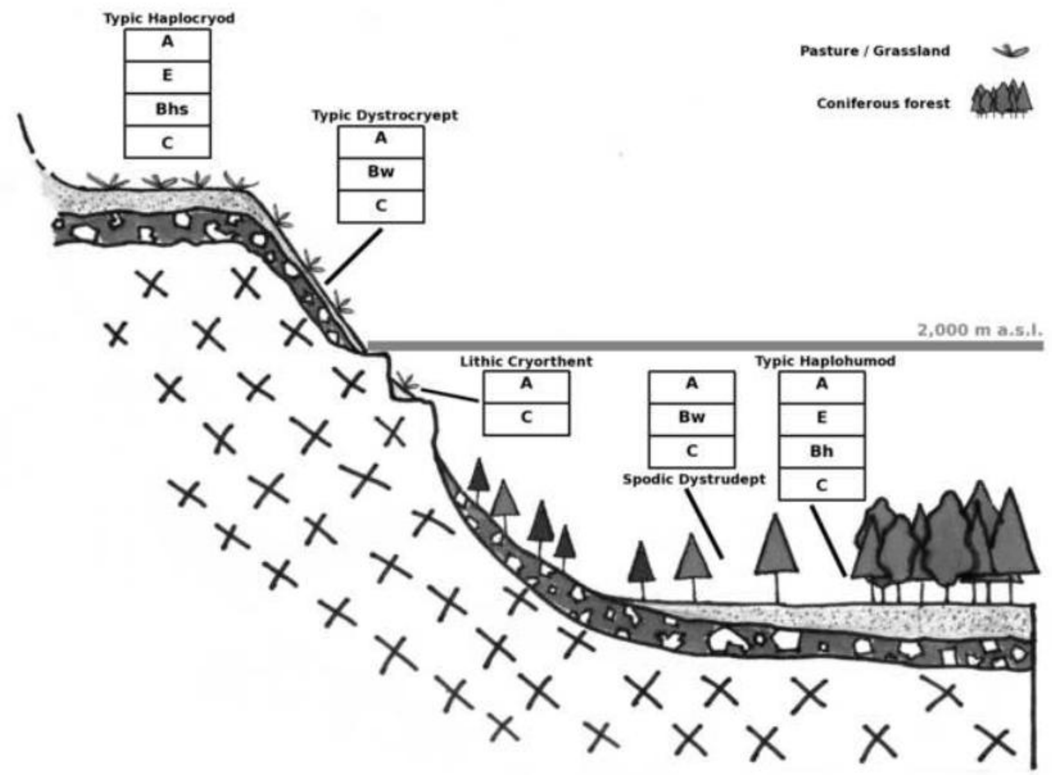
Typic Haplocryod
A
E
Bhs
C
Typic Dystrocryept
A
Bw
C
Pasture / Grassland
Coniferous forest
2,000 m a.s.l.
Lithic Cryorthent
A
C
A
Bw
C
Spodic Dystrudept
Typic Haplohumod
A
E
Bh
C

Fig. 9

Table 1
Extensions and elevation ranges of studied sites.

SITE NAME	PROVINCE	EXTENT (Km^2)	ELEVATION RANGE (m a.s.l.)
Paneveggio-Pale S. Martino Regional Park	Trento	197	1200 - 2400
Fassa valley	Trento	200	1175 - 2810
Valfredda valley	Belluno	5	1800 - 2400
Gares valley	Belluno	36,5	890 - 3192
Cortina d'Ampezzo territory	Belluno	255	1224 - 3244
Visdende valley	Belluno	70	1250 - 2700

Table 2
Codes and decodes of discrete variables classes analyzed by MCA.

Suborders		**Vegetation cover**		**Total number of horizons**		**Parent material**	
Code	**Decod.**	**Code**	**Decod.**	**Code**	**Decod.**	**Code**	**Decod.**
Subord1	*Udepts*	I	*Coniferous forest*	H1	*1*	I	*Calcareous rocks*
Subord2	*Rendolls*	II	*Mixed forest*	H2	*2*	II	*Siliceous rocks*
Subord3	*Orthents*	III	*Shrub*	H3	*3*	III	*Calcareous debris*
Subord4	*Cryepts*	IV	*Meadow*	H4	*4*	IV	*Siliceous debris*
Subord5	*Cryods*	V	*Grassland*	H5	*5*	V	*Arenaceous and mixed debris*
Subord6	*Humods*	VI	*Pasture*	H6	*6*	VI	*Other calcareous sedimentary rocks*
Subord7	*Hortods*	VII	*Wet meadow*	H7	*7*		
Subord8	*Saprists*						
Subord9	*Hemists*						
Subord10	*Udolls*						

Table 3
Taxonomic sketch of the investigated soils (Soil Survey Staff, 2010) and their abundance at Order level.

Orders	**Abundance %**	**Suborders**	**Groups**	**Subgropus**
Entisols	43	*Orthents*	*Cryorthents*	*Lithic/Typic/Aquic*
			Udorthents,	*Lithic/Typic/Aquic*
		Aquents	*Endoaquents*	*Typic*
Inceptisols	36	*Cryepts*	*Haplocryepts*	*Typic*
			Humicryepts	*Typic*
			Dystrocryepts	*Typic*
		Udepts	*Eutrudepts*	*Lithic/Typic/Aquic/Dystric/Aquic Dystric/Rendollic*
			Dystrudepts	*Lithic/Humic Lithic/Humic/Typic/Spodic*
Spodosols	9	*Cryods*	*Placocryods*	*Typic*
			Haplocryods	*Entic/Typic*
		Orthods	*Haplorthods*	*Lithic/Entic Lithic/Typic*
		Humods	*Haplohumods*	*Lithic/Typic*
Mollisols	9	*Rendolls*	*Haprendolls*	*Lithic/Typic/Inceptic*
			Cryrendolls	*Lithic/Typic*
Histosols	3	*Hemists*	*Haplohemists*	*Hydric*
		Fibrists	*Haplofibrists*	*Hydric/Fluvaquentic*
		Saprists	*Haplosaprists*	*Typic*

Table 4
Comparison between land evaluations results for each mapping unit.

Mapping units	**Soil Erosion Risk**	**Suitability for mass tourism**	**Suitability for forestry**
1 - Not detected area (city center, mining areas, water bodies)	Non detected area	Non detected area	Non detected area
2 - Calcareous rocky outcrops	Extremely high	N	N
3 - Siliceous rocky outcrops	Extremely high	N	N
4 - Other calcareous sedimentary rocky outcrops	Extremely high	N	N
5 – Debris outcrops	Extremely high	N	N
6 Mixed area composed of rocky outcrops and Lithic Cryrendolls or Lithic and Typic Cryorthents. Elevation above 2000 m. Low or medium slope, Predominant land use: high-altitude grasslands mixed with calcareous rocky outcrops.	High	N	N
7 - Complex of Lithic Cryorthents and Lithic Cryrendolls. Elevation above 2000 m. Low or medium slope, Predominant land use: shrubbery with dominance of mountain pine. Calcareous rocks and debris.	Moderate	N	N
8 - Consociation of Lithic Cryrendolls. Elevation above 2000 m. Low or medium slope, Predominant land use: from sparse to very dense forest with dominance of spruce, larch and swiss pine. Calcareous rocks.	Low	S3	S2s
9 - Complex of Entic Haplocryods and Typic Placocryods. Elevation above 2000 m. Low slope, Predominant land use: high-altitude grassland mixed with siliceous rocky outcrops. Sandstones.	Moderate	S3	N
10 - Consociation of Typic Eutrocryepts. Elevation above 2000 m. High or medium slope, Predominant land use: from sparse to very dense forest with dominance of larch and Swiss pine, replaced by heather moorland at higher altitudes and in stations characterized by strong slope. Siliceous sedimentary rocks.	Moderate	S3	S3sc
11 - Complex of Typic Eutrocryepts and Lithic Cryorthents on buried Haplocryepts. Elevation above 2000 m. Medium slope, Predominant land use: high-altitude grassland mixed with rocky outcrops. Calcareous marlstones and other calcareous sedimentary rocks.	High	N	N
12 - Consociation of Lithic (Dystric) Eutrocryepts. Elevation above 2000 m. Low slope. Predominant land use: high-altitude pasture. Limestones and sandstones.	Low	S3	S2s

13 - Association of Dystric Eutrocryepts and Lithic Cryorthents. Medium slope. Elevation above 2000 m. Predominant land use: forests with dominance of larch and Swiss pine or, secondarily, spruce; shrubs with dominance of mountain pine at higher elevations and at stations with higher slope. Marlstones and other sedimentary rocks.	Low	S3	S3sc
14 - Mixed area composed of debris outcrops and Typic Cryorthents on buried Eutrocryepts. Low or medium slope. Elevation above 2000 m. Predominant land use: high-altitude grassland mixed with calcareous debris outcrops. Calcareous and mixed sandy-pelitic debris.	High	N	N
15 - Association of Lithic and Typic Cryorthents and Typic Eutrocryepts. Low or medium slope. Elevation above 2000 m. Predominant land use: high-altitude pasture. Calcareous and mixed sandy-pelitic debris.	Moderate	S3	S2s
16 - Association of Lithic and Typic Cryorthents and Typic Eutrocryepts. Low and medium slope. Elevation above 2000 m. Predominant land use: shrubbery with dominance of mountain pine. Calcareous debris.	High	N	S3sc
17 - Association of Lithic and Typic Cryrendolls, Lithic and Typic Haplocryolls and, secondarily, Aquic Cryorthents on depressed areas or on fine materials. Low slope. Elevation above 2000 m. Predominant land use: from sparse to very dense forests with dominance of spruce, larch and swiss pine. Calcareous debris.	Moderate	N	S1
18 - Complex of Lithic and Dystric Eutrocryepts, Lithic and Typic Dystrocryepts. Medium or low slope. Elevation above 2000 m. Predominant land use: from sparse to very dense forests with dominance of larch and swiss pine or spruce or, secondarily, scots pine on drier slopes. Mixed sandy-pelitic calcareous debris.	Moderate	S2	S2s
19 - Association of Inceptic Haprendolls and Lithic Udorthents. Medium or low slope. Elevation below 2000 m. Predominant land use: from sparse to very dense forests with dominance of larch and swiss pine or spruce or, secondarily, scots pine on drier slopes. Calcareous debris.	Moderate	S2	S2s
20 - Association of Aquic Eutrudepts, Typic Haprendolls and Typic Udorthents. Low slope. Elevation below 2000 m. Predominant land use: from sparse to very dense forests with dominance of larch and swiss pine or spruce or, secondarily, scots pine on drier slopes. Calcareous debris.	Moderate	S1	N
21 - Association of Typic Udorthents, Typic and Aquic Eutrudepts and, secondarily, Hydric Haplohemists in depressed areas. Low slope. Elevation below 2000 m. Predominant land use: mown meadow. On calcareous or mixed debris.	Moderate	S1	N
22 - Consociations of Aquic Cryorthents. Low or no slope. Elevation above 2000 m. Predominant land use: high-elevation pasture. Fine lacustrine materials.	Low	S1	S2s

23 - Complex of Typic Eutrudepts and Rendollic Eutrudepts. Low or no slope. Elevation below 2000 m. Predominant land use: forests and meadows dominated by scots pine. Mixed siliceous and calcareous alluvial gravels.	Low	S1	S2s
24 - Complex of Typic Cryaquents and Fluvaquentic and Hydric Cryohemists. No slope. Elevation above 2000 m. Predominant land use: high-elevation wet meadows, associated with pasture or sparse forests. Tectonic depressions, sinkholes or other depressed areas.	No risk	S2	S2s

Table 5
Percentages of areas affected by different erosion risk and characterized by different suitability for forestry and for touristic land use in the Cortina valley (Bini and Zilioli, 2010).

Soil Erosion Risk	**Area %**
Areas with extremely high risk	21,5
Areas with high risk	15,3
Areas with moderate risk	50,2
Areas with low risk	11,4
Areas without risk	0,05
Areas not surveyed	1,5
Suitability for forestry	**Area%**
Not detected area	1,5
Very suitable – S1	10,5
Moderately suitable - S2s (soil properties restrictions)	28,3
Scarcely suitable - S3sc (soil properties and climatic restrictions)	8,3
Not suitable - N	51,4
Suitability for mass tourism	**Area%**
Very suitable – S1	11,2
Moderately suitable S2	18,9
Scarcely suitable - S3	13,2
Not suitable - N	56,6